

**Study of Lateral Adherence Thresholds for
User Request Evaluation Tool
Core Capability Limited Deployment
Accuracy Acceptance Testing**

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Executive Summary

The required number of valid aircraft to aircraft encounters at each separation interval bin is 506 encounters. An encounter is valid only if the preceding track reports have been continuously in lateral adherence for a parameter time. The July Initial Delivery included five scenarios in an attempt to meet the required number of encounters. The Initial Delivery used the default lateral adherence thresholds based on the HCS OUTLAT function [1][2]. Unfortunately, the Initial Delivery's final encounter count with adherence indicated a sixth scenario would be needed for the Final Delivery. Larger thresholds can be used to increase the number of encounters in adherence. This study examined the actual lateral adherence distance distribution for two of the five Initial Delivery Scenarios to determine more applicable thresholds.

The lateral adherence distance is the deviation laterally between a track report and its current cleared route. The distribution of the lateral adherence distances of Host track reports was used to determine new lateral adherence thresholds. This study defines the lateral adherence distribution as the cumulative number of track reports as a function of lateral adherence distance. For each of the two scenarios identified, the distribution of lateral adherence distances was examined at the 90th, 97th, and 99th quantiles. Thresholds were chosen at each of these quantiles.

Encounter counts were then evaluated for each of the three chosen quantiles. Using the default thresholds for the current plan parameters, only 44 percent of the encounters are valid after adherence is applied. Using the corresponding 90th, 97th, and 99th quantile thresholds, the percent of valid encounters for the two scenarios examined in this study were 49, 61, and 65 percent, respectively. The major increase in valid encounters occurs when the thresholds are increased from their default values to the 97th quantile. Therefore, the encounter counts suggest using the 97th quantile as the new thresholds for the Final Delivery.

The 97th quantile thresholds had the largest impact on encounter counts with the smallest increase in lateral adherence thresholds as compared to the other quantiles. The enroute lateral thresholds increase from about 10 nautical miles maximum to 20 nautical miles for the 97th and to as much as 30 nautical for the 99th quantile. For about the same increase in threshold distances, the increase in encounters between the default to the 97th quantile was three times larger as compared to the impact from the larger thresholds from the 97th to the 99th quantile. In conclusion, the recommended thresholds are listed in the table below. These values are a smoothed set of the 97th quantile's thresholds.

Recommended Lateral Adherence Thresholds

| Altitude (100's of feet) | Enroute (nm) | Turn (nm) |
|-----------------------------|--------------|-----------|
| H <= 100 | 13 | 11 |
| 100 < H <= 180 | 16 | 13 |
| 180 < H <= 330 | 19 | 13 |
| 330 < H | 19 | 14 |

1 Introduction

1.1 Background

The Federal Aviation Administration (FAA) has contracted with the Lockheed Martin Corporation Air Traffic Management Division (LMATM) to develop and deploy a conflict probe decision support tool. The tool is known as the User Request Evaluation Tool Core Capability Limited Deployment (URET CCLD) and is to be deployed at seven Enroute Air Traffic Control Centers (ARTCCs) to meet the FAA's Free Flight Phase One objective. The URET CCLD application is based on the MITRE developed URET Daily Use system currently installed in the Indianapolis and Memphis ARTCCs.

The FAA has tasked ACT-250, the Engineering and Integration Branch located at the FAA W. J. Hughes Technical Center, to supply LMATM with scenarios of realistic air traffic to perform acceptance testing of their system. Air traffic data was collected from the Indianapolis and Memphis ARTCCs by AOS-610, ACT-200, and MITRE on May 26 and 27, 2000. ACT-250 is modifying the recorded data to induce aircraft encounters while maintaining the original flight routes and aircraft profiles. An initial scenario delivery was provided in July 2000 and the Final Accuracy Scenario Delivery and Refresh is planned for November 2000.

1.2 Purpose

This document describes a study by ACT-250 to determine a set of lateral adherence thresholds for the Final Accuracy Scenario Delivery and Refresh. The default thresholds used for the July Initial Accuracy Scenario Delivery were taken from the NAS documentation for the Host Computer System's (HCS) OUTLAT function [2]. An analysis of the Initial Delivery indicated that the number of induced encounters needed to be increased to meet minimum requirements. It is hypothesized that an increase in the lateral adherence thresholds will be sufficient to meet the required number of encounters.

1.3 Scope

The scenarios used for this study were the first and last July Initial Delivery Scenarios, 1100 to 1600 and 1500 to 2000, respectively. The study examined the distribution of lateral adherence for the two input scenarios, identified thresholds that remove outliers at increasing quantiles drawn from these distributions, and determined the impact on the encounter counts. Thresholds for the November Final Delivery will be based on this study.

1.4 Document Organization

Following the Introduction, Section 2 provides an overview of the aircraft traffic data used for this study and the default lateral adherence thresholds. Section 3 describes the statistical analysis used to determine the lateral adherence deviations. Section 4 presents the resulting count of aircraft to aircraft encounters for a range of lateral thresholds. Section 5 provides threshold recommendations and Appendix A contains the statistical plots used in this study.

2 Data and Initial Thresholds

The track data selected for analysis was the 1100-1600 and the 1500-2000 hours scenarios provided in the July Initial Accuracy Scenario Delivery. Using ACT-250 tools, the lateral deviation between track point and the associated cleared route was tabulated and then grouped by altitude band and either enroute or turn phase of flight. This segmentation produced eight distinct data sets for each scenario.

Lateral adherence is a measure of whether a flight is flying its cleared and intended route. Thresholds are used to indicate when a flight is essentially off course. The lateral distance between track and route can be determined as the perpendicular distance between a selected track point and the associated route. The initial adherence thresholds used in analyzing the July Initial Delivery were those of the HCS OUTLAT function. Additional information on adherence to air traffic control clearance as utilized in this study can be found in reference [1].

Table 1 identifies the altitude bands and the default lateral adherence thresholds used in this study.

Table 1: Identification of Altitude Bands and Initial Lateral Adherence Thresholds [1]

| Altitude (100's of feet) | Enroute (nm) | Turn (nm) |
|-----------------------------|--------------|-----------|
| $H \leq 100$ | 4 | 8 |
| $100 < H \leq 180$ | 6 | 10 |
| $180 < H \leq 330$ | 8 | 12 |
| $330 < H$ | 10 | 14 |

3 Statistical Analysis

Initial exploratory data analysis using the lateral deviation of the track points about the cleared route indicated that the data was not normally distributed and actually skewed in a positive direction. This nonlinearity suggested using a boxplot with the absolute value of the lateral deviation and the provided quantiles in the upper range of the data to establish thresholds. Figure 1 is an example of the boxplot provided by SAS-JMP [3] for the 1100-1600 hours scenario with a altitude band below 10,000 feet and the enroute phase of flight. A description of the boxplot will not be provided except to indicate that a lateral threshold of 7.349 nautical miles captured 90 percent of the track data for this sample. Eight plots covering each altitude band and phase of flight combination were determined for both scenarios and are provided in Appendix A.

Figure 1: Example of SAS-JMP Boxplot and Quantiles

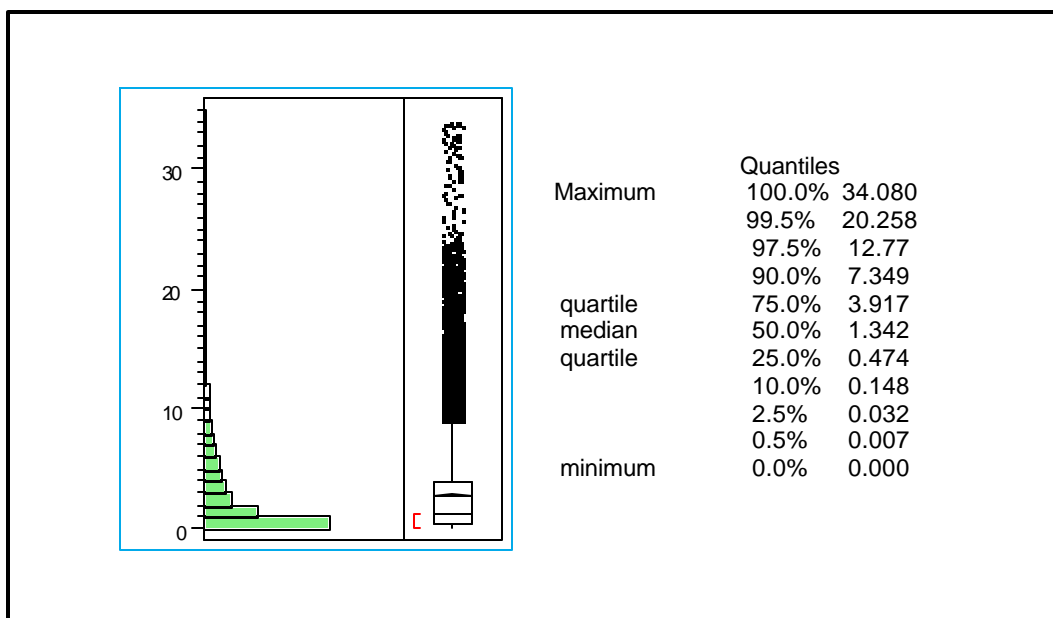


Table 2 presents the larger threshold value of the two data sets for each altitude band and phase of flight combination. These values are in units of nautical miles and were rounded up to the nearest integer. The percentage categories in Table 2 represent the upper range quantiles provided in the boxplots.

Table 2: Maximum Enroute and Turn Threshold Values

| Associated Altitude | Enroute | | | Turn | | |
|---------------------|---------|-------|-------|------|-------|-------|
| | 90% | 97.5% | 99.5% | 90% | 97.5% | 99.5% |
| H <= 100 | 8 | 13 | 21 | 8 | 11 | 13 |
| 100 < H <= 180 | 9 | 16 | 25 | 9 | 13 | 15 |
| 180 < H <= 330 | 9 | 19 | 30 | 9 | 12 | 15 |
| 330 < H | 8 | 18 | 29 | 9 | 11 | 14 |

4 Count of Aircraft Encounters

To qualify as an encounter an aircraft must be in lateral adherence prior to violating minimum separation standards. Additionally, for the two types of flight plans, current plan and trial plan, the aircraft is required to be in adherence for 13 minutes or 20 minutes, respectively, prior to encounter. The values listed in Table 2 provide lateral thresholds that will include a large percentage of the available track data within the adherence time requirements.

Tools developed by ACT-250 can provide a count of aircraft to aircraft encounters for selected minimum horizontal separation distances. Tables 3 and 4 present the encounter counts using the determined threshold values for scenario hours 1100-1600 partitioned by minimum horizontal separation distances. Tables 5 and 6 provide the encounter count for scenario hours 1500-2000. The tables are further categorized by flight plan.

Table 3: Count of Current Plan Aircraft Encounters for Hours 1100-1600

| Minimum Horizontal Separation (nm) | Without Adherence | With Default Threshold | 90.0% of Tracks | 97.5% of Tracks | 99.5% of Tracks |
|------------------------------------|-------------------|------------------------|-----------------|-----------------|-----------------|
| $0 \leq d < 5$ | 213 | 103 | 106 | 136 | 145 |
| $5 \leq d < 10$ | 235 | 112 | 121 | 149 | 153 |
| $10 \leq d < 15$ | 315 | 154 | 162 | 205 | 210 |
| $15 \leq d < 23$ | 605 | 285 | 300 | 382 | 393 |
| $23 \leq d < 30$ | 502 | 226 | 249 | 312 | 333 |
| Total | 1870 | 880 | 938 | 1184 | 1234 |

Table 4: Count of Trial Plan Aircraft Encounters for Hours 1100-1600

| Minimum Horizontal Separation (nm) | Without Adherence | With Default Threshold | 90.0% of Tracks | 97.5% of Tracks | 99.5% of Tracks |
|------------------------------------|-------------------|------------------------|-----------------|-----------------|-----------------|
| $0 \leq d < 5$ | 213 | 98 | 99 | 135 | 144 |
| $5 \leq d < 10$ | 235 | 100 | 112 | 142 | 147 |
| $10 \leq d < 15$ | 315 | 135 | 145 | 191 | 199 |
| $15 \leq d < 24$ | 681 | 295 | 313 | 406 | 423 |
| $24 \leq d < 30$ | 426 | 174 | 194 | 253 | 271 |
| Total | 1870 | 802 | 863 | 1127 | 1184 |

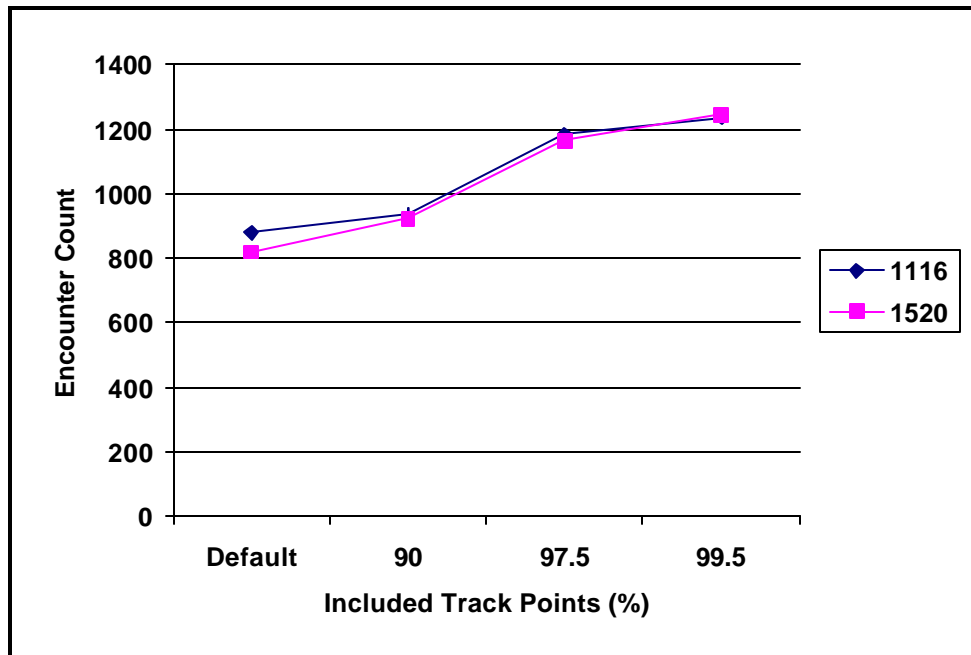
Table 5: Count of Current Plan Aircraft Encounters for Hours 1500-2000

| Minimum Horizontal Separation (nm) | Without Adherence | With Default Threshold | 90.0% of Tracks | 97.5% of Tracks | 99.5% of Tracks |
|------------------------------------|-------------------|------------------------|-----------------|-----------------|-----------------|
| $0 \leq d < 5$ | 206 | 90 | 94 | 116 | 126 |
| $5 \leq d < 10$ | 245 | 99 | 113 | 143 | 151 |
| $10 \leq d < 15$ | 353 | 137 | 154 | 204 | 218 |
| $15 \leq d < 23$ | 643 | 275 | 316 | 401 | 421 |
| $23 \leq d < 30$ | 515 | 218 | 245 | 300 | 328 |
| Total | 1962 | 819 | 922 | 1164 | 1244 |

Table 6: Count of Trial Plan Aircraft Encounters for Hours 1500-2000

| Minimum Horizontal Separation (nm) | Without Adherence | With Default Threshold | 90.0% of Tracks | 97.5% of Tracks | 99.5% of Tracks |
|------------------------------------|-------------------|------------------------|-----------------|-----------------|-----------------|
| $0 \leq d < 5$ | 206 | 85 | 88 | 108 | 117 |
| $5 \leq d < 10$ | 245 | 89 | 103 | 132 | 139 |
| $10 \leq d < 15$ | 353 | 127 | 141 | 197 | 211 |
| $15 \leq d < 24$ | 725 | 295 | 338 | 436 | 462 |
| $24 \leq d < 30$ | 433 | 162 | 183 | 234 | 258 |
| Total | 1962 | 758 | 853 | 1107 | 1187 |

Figures 2 and 3 plot the total encounter counts for the default and selected quantiles. Figure 2 plots the total count given the current plan time restriction and Figure 3 for the trial plan restriction.

**Figure 2: Count of Encounters by Percentage of Included Tracks for Current Plan**

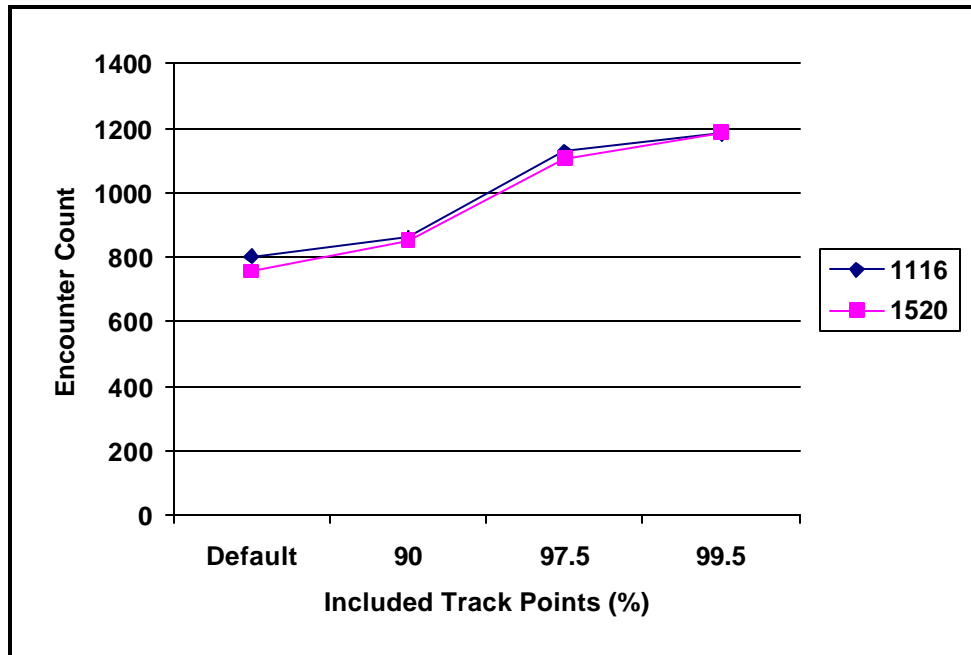


Figure 3: Count of Encounters by Percentage of Included Tracks for Trial Plan

5 Conclusion

By analyzing the counts provided in Tables 3 through 6, thresholds based on a quantile of at least 97.5 percent will meet the encounter requirements for all minimum horizontal separation bins. The 90 percent quantile only slightly increased the count above that provided using the default thresholds. The count derived from the 99.5 percent quantile did not significantly increase the count as the threshold approaches inclusion of all data points. These conclusions are supported by Figure 4, which plots the percent increase in encounter count above the default count for each quantile run.

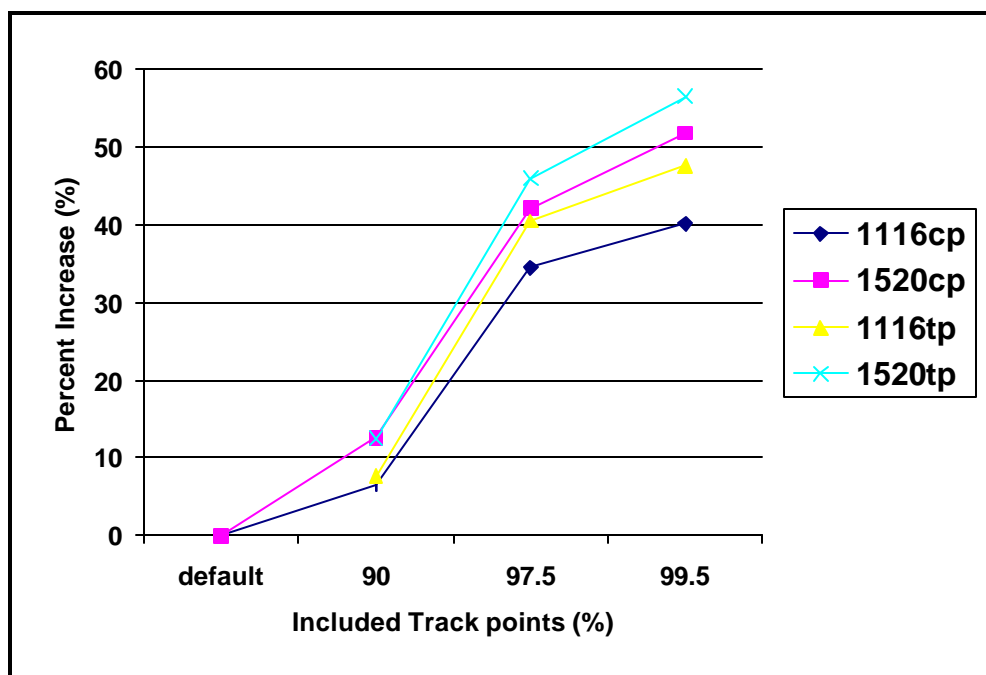


Figure 4: Percent Increase in Encounters Beyond Default Value

The recommended thresholds based on these two scenarios are presented in Table 7. These values are a smoothed set of the 97.5th quantile thresholds as listed in Table 2.

Table 7: Recommended Lateral Adherence Thresholds

| Altitude (100's of feet) | Enroute (nm) | Turn (nm) |
|-----------------------------|--------------|-----------|
| H ≤ 100 | 13 | 11 |
| 100 < H ≤ 180 | 16 | 13 |
| 180 < H ≤ 330 | 19 | 13 |
| 330 < H | 19 | 14 |

References

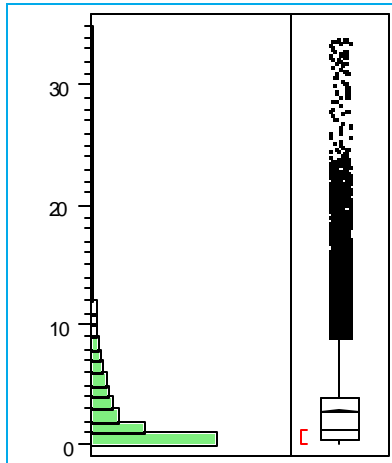
[1] Paglione,M., Oaks,R., Ryan,Dr.H., Summerill,J.S., (Final, January 2000), *Description of Accuracy Scenarios for the Acceptance Testing of the User Request Evaluation Tool (URET) / Core Capability Limited Deployment (CCLD)*, FAA William J. Hughes Technical Center / ACT-250, Atlantic City, New Jersey.

[2] Federal Aviation Administration (April 1998), National Airspace System Enroute Configuration Management Document Computer Program Functional Specifications Route Conversion and Posting, Model A4e2.1, NAS-MD-312.

[3] SAS Institute, JMP Statistics and Graphics Guide, Version 3, JMP Software Package, 1995.

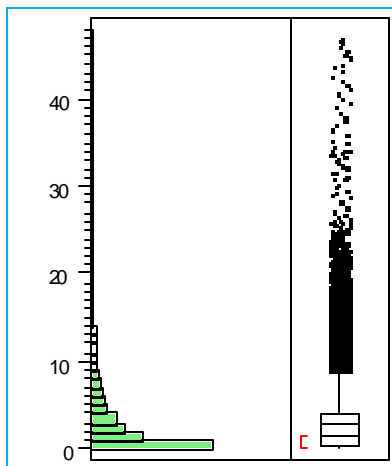
Appendix A: JMP Boxplots for Scenario Data

1116 0H100 Enroute



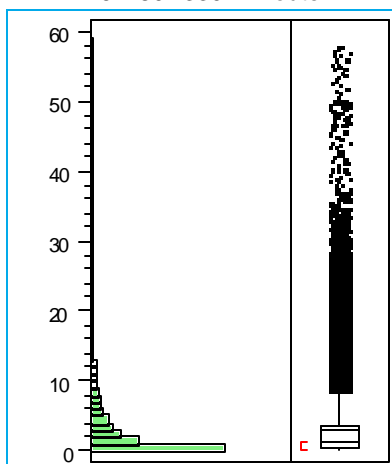
| | Quantiles | |
|----------|-----------|--------|
| Maximum | 100.0% | 34.080 |
| | 99.5% | 20.258 |
| quartile | 97.5% | 12.77 |
| | 90.0% | 7.349 |
| | 75.0% | 3.917 |
| | 50.0% | 1.342 |
| | 25.0% | 0.474 |
| | 10.0% | 0.148 |
| minimum | 2.5% | 0.032 |
| | 0.5% | 0.007 |
| | 0.0% | 0.000 |

1116 100H180 Enroute



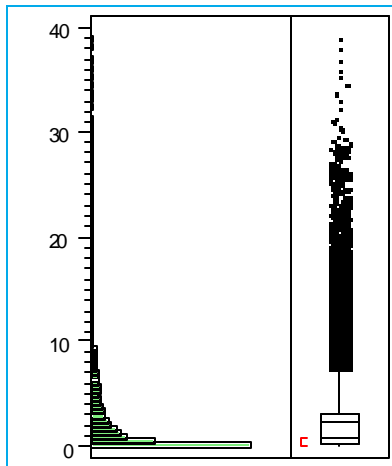
| | Quantiles | |
|----------|-----------|--------|
| Maximum | 100.0% | 47.070 |
| | 99.5% | 21.666 |
| quartile | 97.5% | 14.436 |
| | 90.0% | 8.161 |
| | 75.0% | 3.932 |
| | 50.0% | 1.559 |
| | 25.0% | 0.467 |
| | 10.0% | 0.157 |
| minimum | 2.5% | 0.041 |
| | 0.5% | 0.009 |
| | 0.0% | 0.000 |

1116 180H330 Enroute



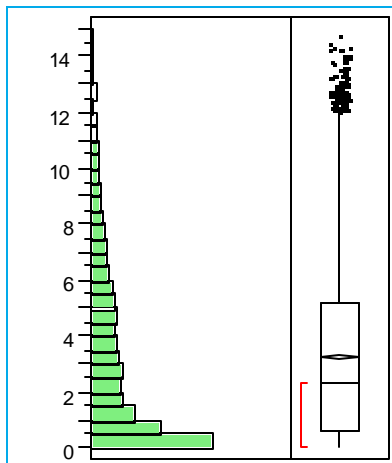
| | Quantiles | |
|----------|-----------|--------|
| Maximum | 100.0% | 58.181 |
| | 99.5% | 26.840 |
| quartile | 97.5% | 16.829 |
| | 90.0% | 8.269 |
| | 75.0% | 3.826 |
| | 50.0% | 1.305 |
| | 25.0% | 0.334 |
| | 10.0% | 0.113 |
| minimum | 2.5% | 0.027 |
| | 0.5% | 0.005 |
| | 0.0% | 0.000 |

1116 330H Enroute



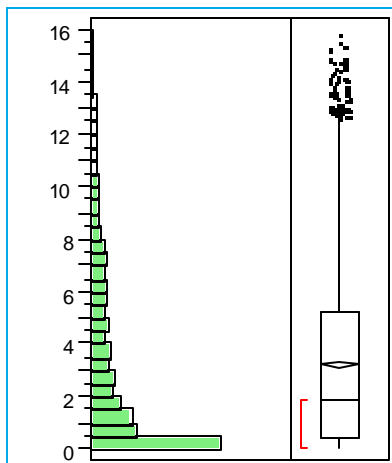
| | Quantiles | |
|----------|-----------|--------|
| Maximum | 100.0% | 39.117 |
| | 99.5% | 19.597 |
| | 97.5% | 13.448 |
| | 90.0% | 6.969 |
| | 75.0% | 3.209 |
| quartile | 50.0% | 0.955 |
| quartile | 25.0% | 0.258 |
| | 10.0% | 0.092 |
| | 2.5% | 0.022 |
| | 0.5% | 0.004 |
| minimum | 0.0% | 0.000 |

1116 0H100 Turn



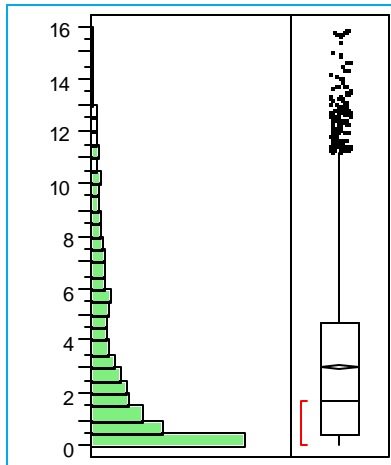
| | Quantiles | |
|----------|-----------|--------|
| Maximum | 100.0% | 14.823 |
| | 99.5% | 12.968 |
| | 97.5% | 10.959 |
| | 90.0% | 7.987 |
| | 75.0% | 5.212 |
| quartile | 50.0% | 2.409 |
| quartile | 25.0% | 0.630 |
| | 10.0% | 0.157 |
| | 2.5% | 0.034 |
| | 0.5% | 0.007 |
| minimum | 0.0% | 0.000 |

1116 100H180 Turn



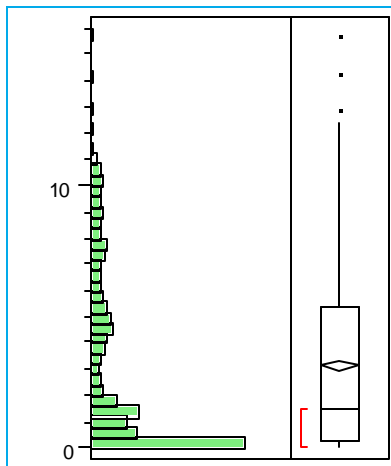
| | Quantiles | |
|----------|-----------|--------|
| Maximum | 100.0% | 15.900 |
| | 99.5% | 14.414 |
| | 97.5% | 12.244 |
| | 90.0% | 8.224 |
| | 75.0% | 5.315 |
| quartile | 50.0% | 1.919 |
| quartile | 25.0% | 0.437 |
| | 10.0% | 0.124 |
| | 2.5% | 0.021 |
| | 0.5% | 0.003 |
| minimum | 0.0% | 0.000 |

1116 180H330 Turn



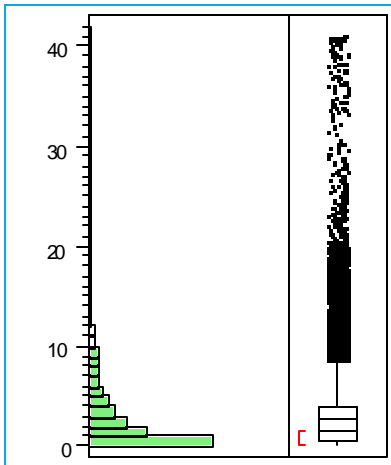
| | Quantiles | |
|----------|-----------|--------|
| Maximum | 100.0% | 15.993 |
| | 99.5% | 14.025 |
| | 97.5% | 11.699 |
| | 90.0% | 8.098 |
| quartile | 75.0% | 4.757 |
| median | 50.0% | 1.719 |
| quartile | 25.0% | 0.462 |
| | 10.0% | 0.149 |
| | 2.5% | 0.032 |
| | 0.5% | 0.009 |
| minimum | 0.0% | 0.000 |

1116 330H Turn



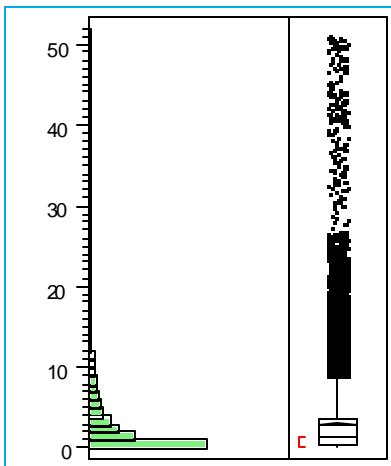
| | Quantiles | |
|----------|-----------|--------|
| Maximum | 100.0% | 15.769 |
| | 99.5% | 12.277 |
| | 97.5% | 10.496 |
| | 90.0% | 8.654 |
| quartile | 75.0% | 5.339 |
| median | 50.0% | 1.523 |
| quartile | 25.0% | 0.316 |
| | 10.0% | 0.102 |
| | 2.5% | 0.015 |
| | 0.5% | 0.001 |
| minimum | 0.0% | 0.000 |

1520 0H100 Enroute



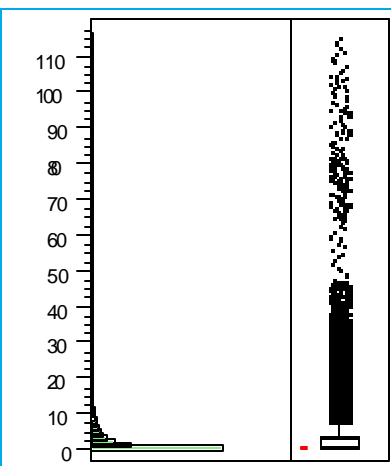
| | Quantiles | |
|----------|-----------|--------|
| maximum | 100.0% | 41.218 |
| | 99.5% | 19.625 |
| | 97.5% | 12.794 |
| | 90.0% | 7.849 |
| | 75.0% | 3.868 |
| quartile | 50.0% | 1.600 |
| quartile | 25.0% | 0.519 |
| | 10.0% | 0.162 |
| | 2.5% | 0.037 |
| minimum | 0.5% | 0.007 |
| | 0.0% | 0.000 |

1520 100H180 Enroute



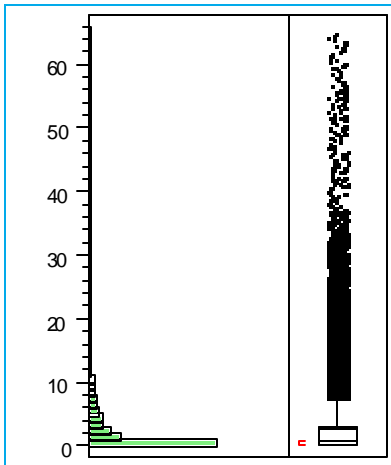
| | Quantiles | |
|----------|-----------|--------|
| maximum | 100.0% | 51.257 |
| | 99.5% | 25.000 |
| | 97.5% | 15.904 |
| | 90.0% | 8.265 |
| | 75.0% | 3.886 |
| quartile | 50.0% | 1.428 |
| quartile | 25.0% | 0.403 |
| | 10.0% | 0.138 |
| | 2.5% | 0.032 |
| minimum | 0.5% | 0.006 |
| | 0.0% | 0.000 |

1520 180H330 Enroute



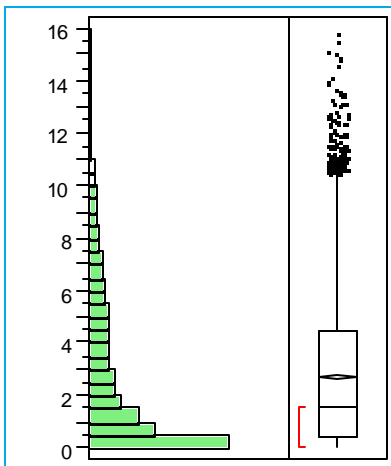
| | Quantiles | |
|----------|-----------|--------|
| maximum | 100.0% | 116.25 |
| | 99.5% | 29.80 |
| | 97.5% | 18.19 |
| | 90.0% | 8.30 |
| | 75.0% | 3.63 |
| quartile | 50.0% | 1.12 |
| quartile | 25.0% | 0.29 |
| | 10.0% | 0.10 |
| | 2.5% | 0.03 |
| minimum | 0.5% | 0.01 |
| | 0.0% | 0.00 |

1520 330H Enroute



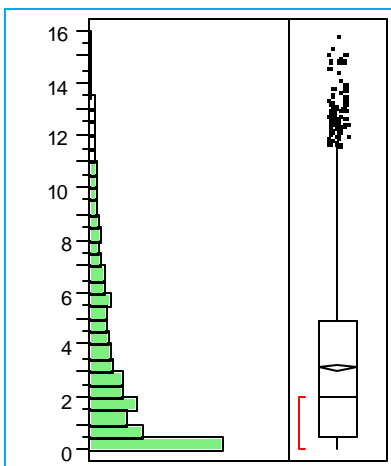
| | | |
|----------|-----------|--------|
| maximum | Quantiles | |
| | 100.0% | 65.276 |
| quartile | 99.5% | 28.925 |
| | 97.5% | 17.801 |
| | 90.0% | 7.728 |
| | 75.0% | 3.219 |
| | 50.0% | 0.865 |
| | 25.0% | 0.216 |
| | 10.0% | 0.075 |
| minimum | 2.5% | 0.019 |
| | 0.5% | 0.004 |
| | 0.0% | 0.000 |

1520 0H100 Turn



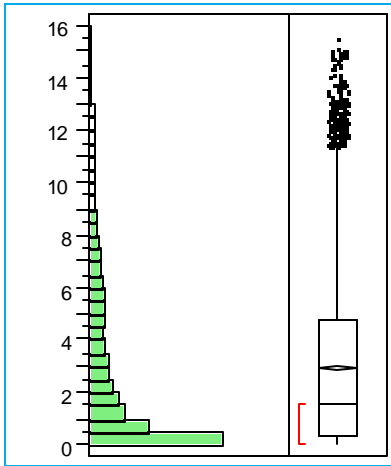
| | | |
|----------|-----------|--------|
| maximum | Quantiles | |
| | 100.0% | 15.875 |
| quartile | 99.5% | 12.324 |
| | 97.5% | 9.867 |
| | 90.0% | 7.031 |
| | 75.0% | 4.461 |
| | 50.0% | 1.558 |
| | 25.0% | 0.431 |
| | 10.0% | 0.133 |
| minimum | 2.5% | 0.028 |
| | 0.5% | 0.005 |
| | 0.0% | 0.000 |

1520 100H180 Turn



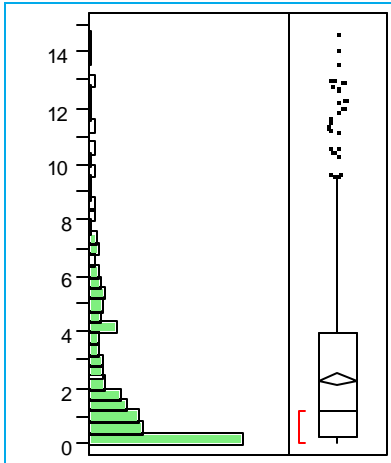
| | | |
|----------|-----------|--------|
| maximum | Quantiles | |
| | 100.0% | 15.841 |
| quartile | 99.5% | 13.472 |
| | 97.5% | 11.398 |
| | 90.0% | 8.050 |
| | 75.0% | 4.987 |
| | 50.0% | 2.087 |
| | 25.0% | 0.522 |
| | 10.0% | 0.149 |
| minimum | 2.5% | 0.034 |
| | 0.5% | 0.006 |
| | 0.0% | 0.000 |

1520 180H330 Turn



| Quantiles | | |
|-----------|--------|--------|
| maximum | 100.0% | 15.561 |
| | 99.5% | 13.951 |
| | 97.5% | 11.940 |
| | 90.0% | 7.769 |
| quartile | 75.0% | 4.797 |
| median | 50.0% | 1.563 |
| quartile | 25.0% | 0.402 |
| minimum | 10.0% | 0.124 |
| | 2.5% | 0.023 |
| | 0.5% | 0.004 |
| | 0.0% | 0.000 |

1520 330H Turn



| Quantiles | | |
|-----------|--------|--------|
| maximum | 100.0% | 14.750 |
| | 99.5% | 13.101 |
| | 97.5% | 10.503 |
| | 90.0% | 6.108 |
| quartile | 75.0% | 4.000 |
| median | 50.0% | 1.150 |
| quartile | 25.0% | 0.263 |
| minimum | 10.0% | 0.083 |
| | 2.5% | 0.020 |
| | 0.5% | 0.005 |
| | 0.0% | 0.002 |